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Digital Terrain Elevations (DTE) that can be rapidly generated, and that have better fidelity and accuracy than Digital Terrain Elevation Data (DTED) Levels 1 or 2, would be extremely beneficial to Department of Defense (DoD) military operations, civil works programs, and various commercial applications. As a result, the Advanced Research Projects Agency (ARPA), along with the U.S. Army Topographic Engineering Center (TEC), are developing an Interferometric Synthetic Aperture Radar (IFSAR) elevation mapping capability. This system, the Interferometric Synthetic Aperture Radar for Digital Radar Elevations (IFSARE), is capable of collecting and providing data in all weathers (reasonable), in day or night scenarios, and where obscurants are present. The IFSARE, which is currently undergoing Integration and Test, will allow for rapid on-line automatic processing of the collected digital radar data into DTE and high quality imagery. The prime contractor is the Environmental Research Institute of Michigan (ERIM). This paper addresses the proof of concept for civil works applications by analyzing a data set taken by the Wright Labs/ERIM Data Collection System (DCS). The objective was to demonstrate the capability of an IFSAR system to provide high fidelity, fine resolution DTE that can be employed in hydraulic models of the Mississippi River watershed. The demonstration was sponsored by ARPA and TEC.

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INTERFEROMETRIC SYNTHETIC APERTURE RADAR AND THE DATA COLLECTION SYSTEM DIGITAL TERRAIN ELEVATION DEMONSTRATION

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BIOGRAPHICAL SKETCH

Robert J. Heidelbach received a Bachelor of Science degree in Engineering of Mines from the West Virginia University (1981). Since June 1984 he has been employed at the U.S. Army Topographic Engineering Center, Alexandria, VA. He has worked on a variety of radar/remote sensing programs during this time, to include the Tactical Radar Correlator (TRAC), the Imagery Processing and Dissemination System (IPDS), and currently, the Interferometric Synthetic Aperture Radar for Digital Terrain Elevations (IFSARE).

Robert Bolus was hired into the position of Physical Scientist in image processing at the RS/GIS Center in May of 1992. He has used ERDAS, Idrisi, Adobe Photoshop, MultiSpec, IDL, and SIPS image processing packages, He has processed Landsat TM, SPOT, ERS-1 SAR, and AVHRR satellite imagery. He has also processed Geoscan, simulated MODIS, CASI, and DMSV airborne imagery. The projects he has been involved in include oil spill detection, wild vegetation classification, flood delineation, and digital elevation determination.

D. John Chadwick received a Bachelor of Science degree in Geology in 1987, and a Master of Science degree in Geology in 1993. He has done geological remote sensing research at the Smithsonian's Center for Earth and Planetary Studies from 1987-89, at the U.S. Geological Survey in Flagstaff, Arizona from 1990-1994, and has recently started work at the Remote Sensing/GIS Center in Hanover, New Hampshire.

ABSTRACT

Digital Terrain Elevations (DTE) that can be rapidly generated, and that have better fidelity and accuracy than Digital Terrain Elevation Data (DTED) Levels 1 or 2, would be extremely beneficial to Department of Defense (DoD) military operations, civil works programs, and various commercial applications. As a result, the Advanced Research Projects Agency (ARPA), along with the U.S. Army Topographic Engineering Center (TEC), are developing an Interferometric Synthetic Aperture Radar (IFSAR) elevation mapping capability. This system, the Interferometric Synthetic Aperture Radar for Digital Radar Elevations (IFSARE), is capable of collecting and providing data in all weathers (reasonable), in day or night scenarios, and where obscurants are present. The IFSARE, which is currently undergoing Integration and Test, will allow for rapid on-line automatic processing of the collected digital radar data into DTE and high quality imagery. The prime contractor is the Environmental Research Institute of Michigan (ERIM). This paper addresses the proof of concept for civil works applications by analyzing a data set taken by the Wright Labs/ERIM Data Collection System (DCS). The objective was to demonstrate the capability of an IFSAR system to provide high fidelity, fine resolution DTE that can be employed in hydraulic models of the Mississippi River watershed. The demonstration was sponsored by ARPA and TEC.

BACKGROUND

Accurate digital terrain elevation data is critical to both military and civil works operations. This data has taken on various names (DTED, DTE, DTEM, DEM, etc.) depending on who compiled the data set (Adkins and Murray, 1994). They are all [illegible] al elevation products.

The Defense Mapping Age[illegible] (DMA) produces Digital Terrain Elevation Data DTED) Levels 1 and 2. Level 1 and 2 accuracy objectives are: absolute horizontal of 50 meters at 90% circular error probable (CEP) and absolute vertical of +/- 30 meters at 90% linear error probable (LEP). The format is ASCII. The difference between the two is the density at which horizontal/vertical values are provided (i.e. post spacings). For level 1 it is every 100 meters, for Level 2 every 30 meters. Level 1 is available for about 60% of the Earth's landmass, whereas Level 2 coverage is extremely sporadic.

The United States Geological Survey (USGS) produces digital elevation data known as Digital Elevation Models (DEM). Vertical accuracy is +/- 7 meters at 30 meter post spacings. The format is ASCII. Coverage is available for about half of the Continental United States (CONUS), and some coverage of Hawaii and Alaska exists.

Civil works operations set the requirements [illegible] cy standards that must be adhered to during project execution. for flood plain mapping of major waterw[illegible]s, for instance, 1 foot vertical contours are desired. As of this writing, traditional photographic methods must [illegible] employed to achieve this level of accuracy. Photographic methods require clear weather, and are very costly and time consuming.

Interferometric Synthetic Aperture Radar (IFSAR) technology has the potential to rapidly provide high fidelity, low cost Digital Terrain Elevations (DTE) for military, civil, and commercial users. A key advantage of radar systems is their ability to collect data under most weather conditions, day or night, and where obscurants are present.

IFSAR technology requires co-registered, complex Synthetic Aperture Radar (SAR) imagery to be taken of a single scene from two apertures in space (Li and Goldstein, 1990). The displacement of the two apertures must have a component normal to the line of sight, and may be achieved by having multiple apertures on the platform or by collecting multiple pass data. This paper will address the former. the elevation angle to each pixel in the SAR image can be determined from the phase difference observed.

The phenomenology associated with radar ultimately affects the quality of the DTE that can be generated by IFSAR techniques. Height accuracy is dependent upon how accurately we can measure differentially phase, which depends upon, among other things, the signal-to-noise ratio (SNR). Subsequently, height accuracy degrades in regions with low or no SNR, such as roads, relatively calm bodies of water, and radar shadowed areas. These area manifest themselves as "black" areas in the imagery and height measurements cannot be determined from them. However, height accuracy in these regions (except shadowed areas) can be improved by increasing the radar sensitivity, for instance, by increasing transmitted power. Different flight geometry can enable data in radar shadowed areas to by collected. Additionally, objects that move, such as vehicles or wind-blown vegetation, tend to be displaced and smeared in the imagery and DTE. Finally, at the frequency of interest, X-band (10 GHz), there is no significant foliage penetration, and therefore the heights of the trees are measured, not the height of the underlying terrain. Foliage penetration could possibly be accomplished by operating at lower frequencies, for example below 1 GHz.

TECHNICAL DESCRIPTION AND SPECIFICATIONS

The Wright Laboratory/Environmental Research Institute of Michigan (ERIM) Data Collection System (DCS) is an interim IFSAR system that has been modified for strip mapping. The DSC is a Convair 580-based X-band IFSAR system with a belly-mounted randome. Wavelength is 0.03 meters. For this collection, valid collection parameters were: altitude - 24,000 feet Mean Sea Level (MSL), depression angle - 45 degrees, collected resolution - 1.1 x 1.1 meters slant range and azimuth, swath width - 1.7 kilometers, baseline separation - 1.0 meter horizontal, polarization - HH. The DCS employs real-time differential Global Positioning System (GPS) technology.

DATA COLLECTION AND PROCESSING

The study was a 3 x 2 kilometer region containing a portion of the floodplain of the Iowa River as it passes through downtown Iowa City, IA (Figure 1). The data were collected on 24 March, 1994, with the DCS flying south and looking west. Note that an area roughly 3 kilometers wide by 12 kilometers long was actually collected, but only the area of interest was processed into DTE and imagery. the total area collected extended from the Coralville Dam in the north to the Iowa City Municipal Airport in the west. Ground truth support was provided by personnel from the Remote Sensing/Geographic Information System Center (RS/GISC), the U.S. Army Corps of Engineers Rock Island District (CENCR), the U.S. Army Topographic Engineering Center (TEC), and ERIM.

All data in the area of interest were post processed by ERIM at Ann Arbor, MI. After spatial averaging, the data were orthorectified and the output products, SAR intensity imagery and the DTE files, were generated at 2 meter post spacings. For the SAR intensity imagery, spatial averaging was done over a 30 x 30 meter area. The processed data consisted of six frames of image data, each 1700 meters ground range by 830 meters azimuth, and six DTE frames of the same size. Overlap, necessary for mosaicking the data, was 500 meters in range by 50 meters in azimuth.

Figure 1. Section of the Iowa City 1:100,000-scale map, showing the 6 image frames covered by the IFSAR in this study. The flight line was from north to south along the eastern border of the study area.

DATA REDUCTION AND PREPARATION

The two sets of data, representing SAR intensity imagery and interferometric-derived DTE, were received from ERIM for each of six regions in the Iowa City area. Both sets of data had 2 meter pixels (post spacings) and were 850 x 415 pixels (1700 x 830 m) in size. Due to the flight geometry, the raw data was oriented south up and west on the right, so vertical and horizontal inversions of the data were required to orient the data with respect to geographical ground coordinated and produce images (Figures 2 and 3). The correspondence in size and resolution between the imagery and DTE allowed for superposition of the data sets and the production of contour maps (Figure 4 and 5). Data reduction and image preparation was performed using Spyglass (Spyglass, Inc.) and Adobe Photoshop (Adobe Systems, Inc.) software packages.

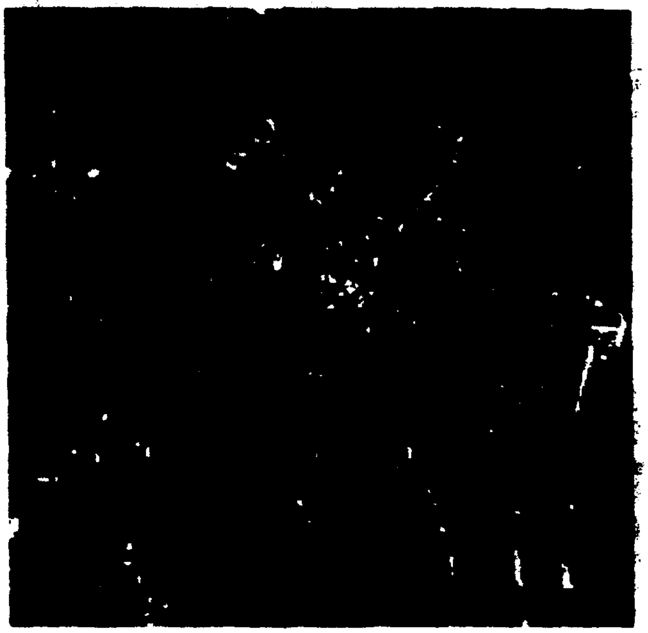

Figure 2. X-band SAR image of part of image frame #1, showing a section of the Iowa River and part of Iowa City. The image is 800 x 800 m.

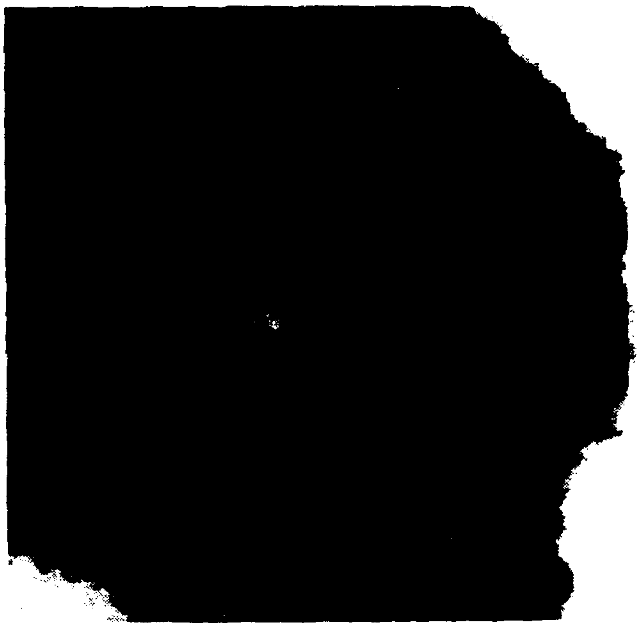

Figure 3. DEM produced from interferometric data. Problems associated with low backscatter and smearing on the river are clearly seen.

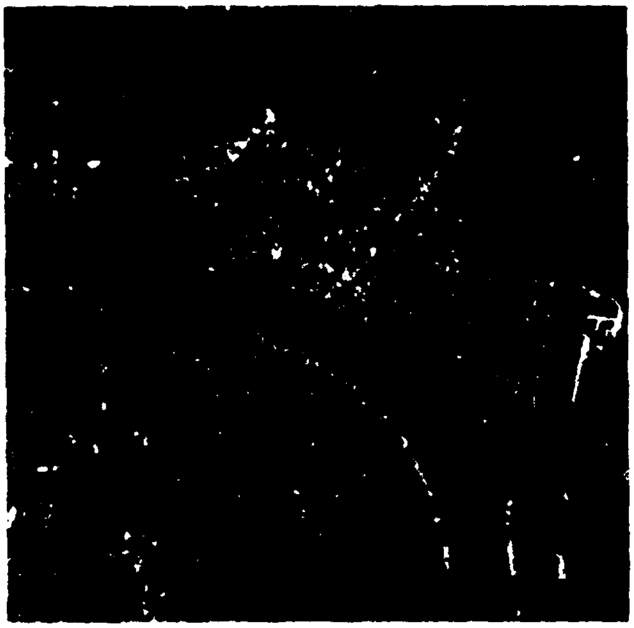

Figure 4. Topographic contours derived from IFSAR elevation data and superposed on SAR image. Contour interal is 20ft.

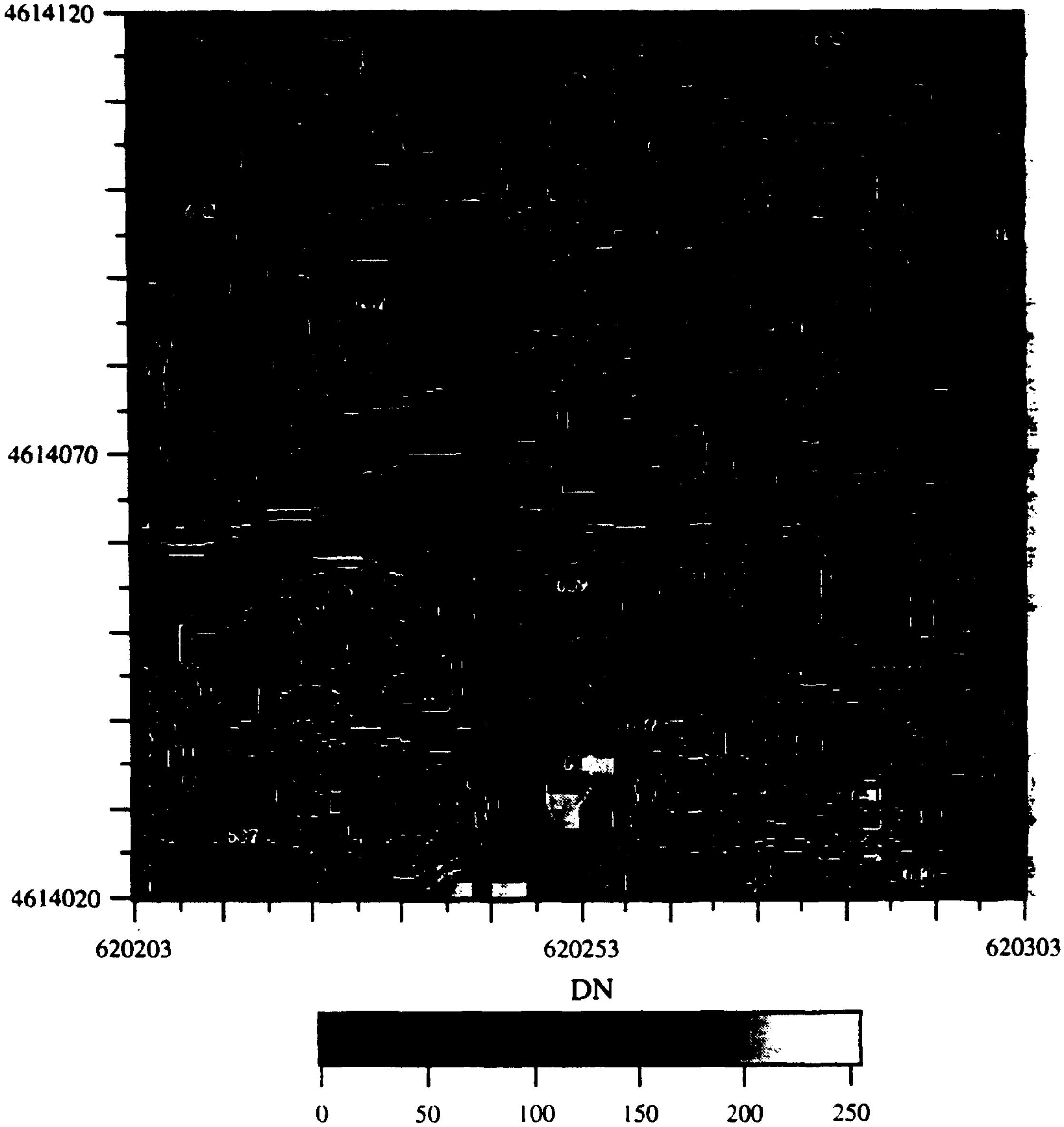

Figure 5. IFSAR-based elevation contours on SAR subimage (100x100 m), part of image frame #4. Contour interval is 1ft. UTM in meters, zone 15.

PERFORMANCE ASSESSMENT

Previous DCS tests had indicated an elevation accuracy of 1.6 meter root mean square (RMS) in an area near Flagstaff, AZ (Giglio, 1994). The Iowa City demonstration provided an additional check on the accuracy of the DCS and IFSR techniques. CENCR surveyed the locations of 11 radar corner reflectors within the study area, and acquired Universal Transverse Mercator (UTM) coordinates (zone 15) and elevation for these points to submeter accuracy. In order to compare the IFSAR-derived DTE values to the surveyed values of the 11 points, the x,y coordinates of the DTE were converted to UTM coordinates, and the z coordinates were converted to meters. The results are shown in Table 1. Vertical errors ranged from -2.13 m to +2.92, with a mean height error of 1.02 m, and an rms error of 1.89 m. Smearing is visible in some portions of Figures 2 and 3, which covers part of image frame 1 (Figure 1). This effect was possible the result of high winds that gusted up to 30 mph during data collection. Wind-clown tree limbs probably caused smearing in the cross-range directions, best seen near the center of Figures 2 and 3 where the river runs along the range (east-west) direction.

Table 1.

Control Point	Northings (m)	Eastings (m)	Surveyed Elevation (m)	IFSAR Elevation (m)	Elevation Difference (m)
1	4615035.7	620842.0	227.64	228.77	1.13
2	4614540.3	620087.6	218.5	216.37	-2.13
3	4614841.4	622074.1	196.81	198.11	1.30
4	4614717.7	621516.4	197.5	198.87	1.37
5	4614129.4	621859.3	199.92	202.19	2.27
6	4614100.7	621510.9	214.98	217.03	2.06
7	4614547.6	621199.9	197.90	200.18	2.28
8	4613861.4	620353.8	198.41	200.24	1.83
9	4613743.4	621553.3	198.06	200.98	2.92
10	4613546.7	619413.2	197.60	197.56	-0.04
11	4614934.8	619756.3	199.97	198.17	-1.80

Backscatter and SNR from water bodies in the data set is too low to reliably extract the phase difference between the two SAR signals. Elevation data on calm bodies of water is therefore unreliable in most areas. This also applies to radar shadowed area.

The X-band SAR used in data collection does not efficiently penetrate a thick foliage canopy, and the presence of deciduous vegetation in warmer months would likely lead to high local aberrations in the topography dataset with respect to winter data collection. The dataset in this study was collected on 24 March 1994, when thick foliage was not yet present.

DISCUSSION AND FUTURE

As stated previously, the data in this study were collected using the DCS, which requires the use of ground control points (supplemental to those in Table 1) for absolute position reference (geolocation) and tile removal. This is a necessary step in the orthorectification process.

The Advanced Research Project Agency (ARPA) and TEC are developing an advanced IFSAR systems, the Interferometric Synthetic Aperture Radar for Digital Terrain Elevations (IFSARE). The goal of the IFSARE program is to develop a single pass IFSAR system capable of rapidly generating low-cost DTE for military and civil works applications.

Unlike the DCS, the IFSARE will not require ground control points. It will be fully calibrated and will require only one surveyed GPS base station within 200 kilometers of the platform. The benefits are that the IFSARE will be able to collect and process data quickly, without waiting for placement or surveying of numerous radar reflectors. The IFSARE's quick turn-around capability will be extremely important when high resolution DTE is required for emergency operations, such as during floods.

The IFSARE is a Learjet-based dual channel X-band IFSAR system with a belly mounted radome. Operating altitude - 40,000 feet MSL, depression angle - 33-52 degrees, collected resolution - 2.5 x .8 meters slant range and azimuth, swath width - 10 kilometers, baseline separation - 1.0 meter horizontal, polarization - HH. The IFSARE employs non real time (post processed) differential/kinematic GPS technology. IFSARE also has a tightly couple Inertial Navigation System (INS)/GPS to allow for control

and compensation (by precisely measuring platform attitude and position) of relative phase errors that are a result of platform motion. Given the IFSARE collection that are a result of platform motion. Given the IFSARE collection (over 100 square kilometers/minute) and processing rates (2.5:1), the system will be able to provide DTE with 5 and/or 10 meter post spacings of an area the size of Massachusetts within a day of tasking.

CONCLUSIONS

The timely production of accurate DTE is possible with remote sensing systems that employ IFSAR techniques to measure the phase difference between two return signals from the same point on the ground.

In this study of the Iowa City, IA area, the IFSAR DTE and SAR intensity imagery of the terrain were found to be generally consistent with eyewitness records, aerial photographs, and USGS maps of the area. The ridges and river flood plains occur in the same locations as on the USGS maps, and the terrain along the river bank is the lowest point in the imagery. The locations of man-made structures such as buildings, roads, and bridges in the SAR intensity imagery were found to be consistent with photos and eyewitness records.

IFSAR-derived height measurements of eleven radar corner reflectors were compared to the heights obtained from conventionally surveying these same points, and the resultant RMS error was 1.89 meters. The maximum vertical error on one point was 2.92 meters. The average vertical error between the interferometrically derived data and the surveyed elevations was 1.02 meters.

ACKNOWLEDGEMENTS

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